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Hygroscopic Aerosol Induced Vapor Scavenging and Deposition from the Inspired Air and Conjugated Changes of Air Temperature and Humidity.

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ON THE HYGROSCOPIC AEROSOL INDUCED VAPOR SCAVENGING AND DEPOSITION FROM THE INSPIRED AIR AND CONJUGATED CHANGES OF AIR TEMPERATURE AND HUMIDUTY.

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ABSTRACT

A quantitative theory has been developed to predict coupled energy and mass transport phenomena during inhalation of hygroscopic aerosol-laden air. It is shown that water vapor condensation on hygroscopic particles during inhalation of aerosol-laden air may result in very non-uniform aerosol induced vapor deposition in the lung. The developed theory is not limited to water vapor and can be applied to other vapor/gas particle-induced scavenging and deposition in the respiratory system.

KEYWORDS

Hygroscopic aerosol; vapor/gas scavenging; lung deposition.

INTRODUCTION

Computer simulations of hygroscopic aerosol deposition in the lung are needed to perform risk assessments and to interpret observed health effects caused by potentially hazardous pollutants. Despite that a great deal of mathematical modeling on total deposition of hygroscopic aerosols has been published (e.g., Persons et al., 1987) no sufficient attention has been given to the local deposition and to the transport effects that particle hygroscopicity may produce. In particular, water vapor entrainment and its local deposition, caused by hygroscopic particles, has not been investigated. Likewise, changes in temperature and humidity in the respiratory system due to coupled mass/heat transport phenomena produced by the hygroscopic aerosol have not been well understood. A mathematical model has been developed to study these effects and preliminary results have been gathered.

RESULTS

Mathematical procedure used in this study has been described extensively elsewhere (Eisner et al., 1988). It is a quantitative theory that predicts coupled energy and mass transport phenomena during inhalation of hygroscopic

aerosol-laden air. It consists of a system of coupled partial differential equations describing temperature and vapor concentration profiles in the aerosol/vapor laden air. Here, the theory has been applied to an airway model of Yeh and Schum, as described in Yu and Diu (1982), adjusted to 3000 cm^3 lung volume. A steady breathing at the rate of 15 cyc/min and 1000 cm^3 tidal volume have been assumed for the purpose of these simulations. An aerosol was a solution of H_2SO_4 in water at the equilibrium mass fraction, stable at 50 % relative humidity and 25 C ambient temperature. Correspondingly, initial particle radius was 1 micron. For the sake of this study we assumed particle number concentration to be 10^5 cm^{-3}. Aerosol deposition due to the gravity and Brownian diffusion has been taken into account. Inertial impaction has not been accounted for, since we have limited our preliminary simulations to a sedentary breathing.

Fig. 1 shows predicted local deposition of the solute (MDEP) and of the solvent (VDEP) in g/cm^2 that may occur during one inhalatory and exhalatory phase, if the particles were non-hygroscopic.

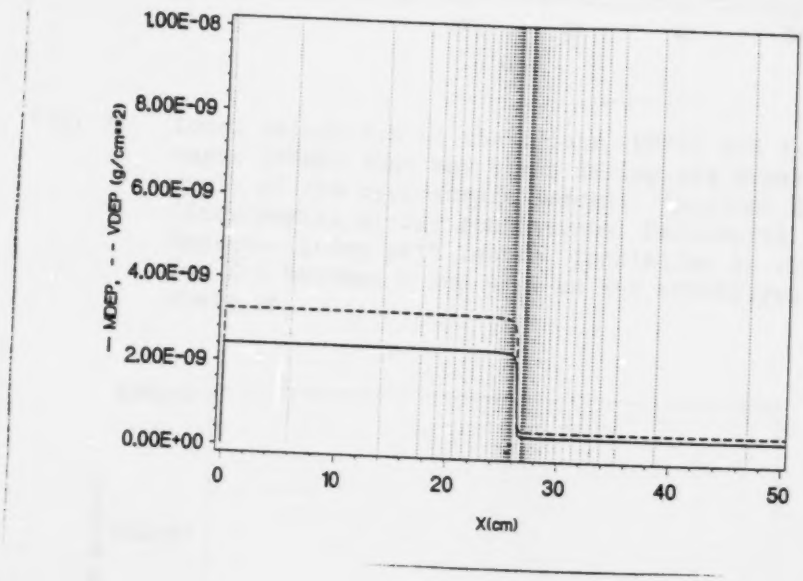

Fig. 1. Local deposition of the solute (MDEP) and the solvent (VDEP) that may occur during one breathing cycle assuming that the aerosol is not hygroscopic. Vertical dotted lines depict airway generations. Horizontal axis depicts airway path length. Inhalation is simulated for X's between 0 and 26.4 cm and exhalation from there on.

Fig. 2 demonstrates solute deposition and particle induced vapor deposition if the hygroscopic growth is accounted for. Fig. 3 shows the same as in Fig. 2

but detailed in the pulmonary region, i.e. airway generations 17 through 23 and X varying between 25.96 cm and 26.40 cm for the inspiration phase.

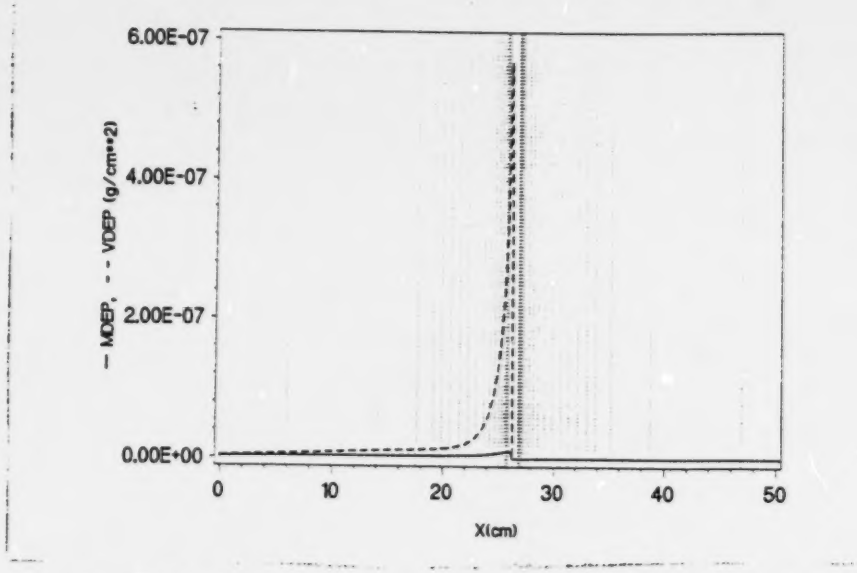

Fig. 2. Local deposition of the solute (MDEP) and the vapor (VDEP) that may occur during one breathing cycle of the hygroscopic aerosol. Vertical dotted lines depict airway generations. Horizontal axis depicts airway path length. Inhalation is simulated for X's between 0 and 26.4 cm and exhalation from there on.

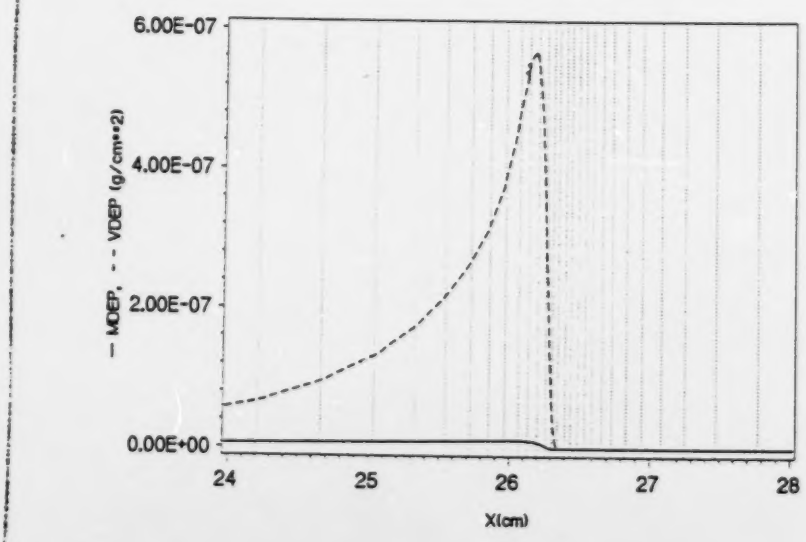

Fig. 3. Blow-up of the pulmonary region from Fig. 2.

In addition to the effects described in these figures we found that hygroscopic growth may cause slight warming of the inhaled air above the body temperature. Also, due to a strong vapor condensation on the particles, relative humidity of the air in the upper tracheobronchial region will be lower compared to the air inhaled free of particles. These last two effects seem to be significant at particle concentration higher than 1000 cm^{-3}.

CONCLUSIONS

In this study we have shown that particle induced vapor deposition may be a very important effect in inhalation toxicology. It is evident that particle induced vapor deposition may be highly non-uniform, and strongly dependant on the mechanisms of vapor scavenging and particle deposition characteristics.

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